DOCUMENT RESUME

ED 269 283 SO 017 005

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TITLE Computer Simulation in Social Science.
PUB DATE 15 Oct 85
NOTE 46p.; Some pages may be marginally legible due to light, broken type.
PUB TYPE Reports - Descriptive (141)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Computer Simulation; *Educational History; Educational Needs; *Educational Trends; Elementary Secondary Education; Microcomputers; Postsecondary Education; Resource Materials; *Social Sciences; Social Studies; Teaching Methods; Trend Analysis

ABSTRACT

From a base in military models, computer simulation has evolved to provide a wide variety of applications in social science. General purpose simulation packages and languages such as FIRM, DYNAMO, and others have made significant contributions toward policy discussion in the social sciences and have well-documented efficacy in instructional settings compared to traditional settings. With the microcomputer revolution has come a revival of computer simulation, first in pre-collegiate education, then in a variety of other areas including urban policy, social processes, and research methodology. In spite of the significant body of research and software in social science it is striking that (1) this research and teaching tradition exists almost entirely outside the "mainstream" of social science journals and textbooks, and (2) the impact of computer simulation has had a relatively greater impact on teaching than research. These findings reflect the state of the social sciences. Attempts at simulation in research-poor environments inevitably lead to models characterized by low reliability, oversimplification, and neglect of causal factors. These three obstacles are the reason why computer simulation has remained a specialized area within social science and is removed from the mainstream practice of social scientists. It is concluded that computer simulation in social science, though a positive way of accumulating knowledge, is apt to remain the step-child it has always been. Over 90 related references conclude the publication. (LH)

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Computer Simulation in Social Science

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SO017005

COMPUTER SIMULATION IN SOCIAL SCIENCE

Computer simulation is the step-child of the behavioral revolution that swept social science after World War II. It is recognized as being part of the family of tools used by social scientists but it is largely hidden well out of the way. It is entirely possible, indeed commonplace, to complete a social science methodology sequence or even a doctoral degree without a serious encounter with computer simulation.

Computer simulation is a topic widely acknowledged to be of importance to social science yet one about which it is difficult to gain information. It is largely omitted from social science textbooks and most of its literature is not published in social science journals. It is the purpose of this essay to bring together some of this literature to provide an overview of computer simulation in social science, its history, its use in teaching and research, and its potential for playing a more significant methodological role in the future.

Social science computer simulation is not a new topic. Two decades ago John Hartman compiled a bibliography of 74 references on social science simulation (1). There have been numerous computer-based instructional materials (2), including simulations (3), widely available since the 1960's, long before the recent microcomputer-based revival of interest in simulation. For those willing to search, even textbook coverage was available. Harold Guetzkow's Simulation in the Social Sciences: Readings appeared

in 1962 (4) while William Coplin's Simulation in the Study of Politics, presenting a dozen computer-related simulations, appeared in 1966 (5). Rand Corporation studies of simulation also have been available since at least 1962 (6). Richard Gonzalez and Claude McMillan's methodology text, Machine Computation: An Algorithmic Approach, treated social science computer simulation fifteen years ago (7). Likewise, a text by Michael Inbar and Clarice Stoll presented 14 case studies of social science simulation in 1972 (8).

Not only is computer simulation in social science not a new topic, but in some ways it is a topic which peaked a over a decade ago during a period of funding agency support. Some simulations were sponsored by the Office of Education under its REACT (Relevant Educational Applications of Computer Technology) program (9) and others through the National Science Foundation's CAUSE and EUCI programs (10), as well as through private agencies such as the EXXON Foundation (11).

Yet in spite of examples of interest in the broader implications of computing for social experimentation (12) it is to military-sponsored efforts that one must turn to find the early popularization of social science computer simulation. For years the Rand Corporation, Abt Associates, the Raytheon Company, Simulmatics Corporation, Consolidated Analysis Centers, the General Research Corporation, the Army War College, the Studies Analysis and Gaming Agency, the National Military Command System Support Center and other governmental and government-contract organizations produced voluminous materials related to the use of computer simulation in national defense and foreign policy

applications.

The Rise of Computer Simulation in National Defense and Foreign Policy Analysis

In the 1961 - 1965 period the Raytheon Corporation developed the TEMPER (Technological, Economic, Military and Political Evaluation Routine) model for the Joint War Games Agency of the Department of Defense (13). This was a model for the analysis of international relations in the context of the 'Cold War', assuming a three-bloc (East, West, Third World) international relations structure as perceived circa 1960. Using a 117 nation data base, TEMPER allowed simulation of the behavior of up to 39 nation-groups at a time. Written in FORTRAN for a CDC 1604B computer, TEMPER incorporated a wide variety of social, economic, political and cultural variables drawn from a 1960 data base (14).

TEMPER was limited by its dependency on mainframe computing, but the advent of time-sharing on mainframe computers was then making possible interactive simulations or 'man-machine models'. Time-sharing meant that computer simulation could be far more widely and efficiently used as a tool for international relations instruction and experimental exploration.

TEMPER was a generalized international relations simulation but numerous more specific models were explored in the 1964-1970 period. These included Abt Associates' ARPA SRU-COIN urban counter-insurgency game under Project AGILE, exploring the feasibility of a computer model of guerrilla warfare (15) ; Rand Corporation's model of border control, infiltration, and

insurgency (16); and General Research Corporation's MINTSIM simulation of tactical nuclear war and conventional military operations in the context of nuclear threat (17).

Also funded with military (ARPA) money, Harold Guetzkow at Northwestern created the Inter-Nation Simulation (INS) in the 1960's. INS evolved into a "man-machine model" in which a computer was used as a message center/randomizer/umpire for a student role-playing game on international relations (18). It had grown out of the tradition of "all-person" role-playing games that had become prominent in international relations and other areas (19). Instructors utilized these games to conduct small group decision-making experiments in a simulated international setting trying to determine, for example, behavior under nuclear threat.

Also at Northwestern, Paul Smoker, working on a subcontract with Harold Guetzkow developed the International Processes Simulation (IPS) as a more complex, second-generation version of INS, further developing a type of man-machine modelling that at that time was coming to be seen as one of the main approaches to international relations as also, for example in William Coplin's World Politics Simulation (WPS) (20). Others carried the concept even further, as in SIPER, an "all-computer" version of INS and one of the first global computer models. (21)

Computer-based international relations simulations were brought into the classroom as well in the early 1970's. For example, Consolidated Analysis Centers, Inc., in 1971 developed a curriculum for the National War College utilizing an

international relations database, statistical analyses, and simulation (22). The following year Kenneth S. Heitzke and Daniel A. O'Donohue introduced military computer gaming experimentally in the curriculum of the Army War College (23).

In 1972 a survey by the Rand Corporation showed some 132 simulations, models, and games in use throughout the Department of Defense(24). However, interest in simulation and gaming peaked around this time, albeit at a rather high level. A 1975 catalog showed 152 simulations and models in use in the Department of Defense, including only two politico-military simulations (26), while the same catalog in 1977 listed only 139 (25). A 1979 Rand study stated that the Department of Defense was allocating $30-$40 million to war modelling, simulation, and gaming (27).

The development of military and foreign policy simulations had been subject to significant criticisms. As early as 1966, M. J. Meeker and G. H. Shure of the System Development Corporation had attributed the failure to make significant research gains through simulation studies to the highly abstract and sterilized nature of the social science which underpinned such models (28).

As late as 1975, even a complex project on long-range environmental forecasting of European environments, undertaken by CACI Inc. for the Advanced Research Projects Agency, utilized a relatively simple model with a dozen equations, least-squares estimation, and stochastic process forecasting (29). After over a decade of military simulations, the models in use often lacked predictive credibility.

From the mid-1970's military and foreign policy simulations

entered a phase in which less emphasis was placed on the research utility of simulation in a scientific sense and more on its utility in policy discussions. As the final technical report on the above-cited CACI Inc. study noted, forecasting models came to be seen as aids to generating meaningful, interesting, alternative futures for discussion in comparison with the strategic implications of contrasting developments (30). On this basis CACI Inc. produced a later report emphasizing politico-military scenario generation for use in a broader policy-making context (31).

This recasting of the purposes of simulation from a determinative to a processual role was much in keeping with other critiques of simulation in social science, notably Hayward R. Alker Jr.'s scathing 1974 article, "Computer Simulations: Inelegant Mathematics and Worse Social Science?" In this article Alker had called for complementing simulation approaches with developmental, philosophical, and mathematical approaches to minimize the abuses of simplistic simulation research (32). Likewise, in 1979 two Rand authors critiqued military simulations and gaming, calling for greater professionalism and improved sensitivity and utility analysis (33).

These critiques are reflected in the best known recent Rand simulation for the military, the Rand Strategy Assessment Center (RSAC) automated wargaming program, a computer simulation with rule-based artificial intelligence features (34). Not intended to serve as a direct guide to military policy akin to intelligence information, RSAC is meant to provide a simulated event

environment which can serve as a basis for discussion and assessment of policy makers' decisions in a developmental process.

Of course, ISAC in many ways reflects a series of earlier efforts in military and foreign policy simulation, particularly those oriented toward curriculum applications. Such earlier efforts had included, for example, the World Politics Simulation of the Industrial College of the Armed Forces (35), intended to convey an appreciation of the problems faced by national leaders.

At the same time, however, classified research at the Department of Defense continued to press ahead with computer simulations. The Joint Chiefs of Staff have recently commissioned a million-dollar world simulation, for example, and the Soviet Union is known to employ such planning models as well (36). In spite of the continuance of such models, however, there was a a tendency toward emphasis on specifically defense simulations rather than the broader sociopolitical ones. This continuing tradition is inaccessible to social scientists lacking security clearance and has thus been widely ignored within the academic community (37).

In general, the military-sponsored studies led those involved to function somewhat as an elite interest group largely talking among themselves and this heavily funded area of social science computing eventually ceased to be seen as a very significant approach to international relations. Many of the unclassified simulations which were developed have languished, relatively unused or unavailable. On the other hand, the North American Simulation and Gaming Association, publishers of

Simulation and Games, has helped keep alive the simulation tradition and are now beginning to move into computerized simulations. A number of others, such as Paul Smoker, are still currently involved in developing new world simulation projects. (38)

It should be emphasized that military contracts were not the sole vehicle for computer simulation in international affairs. In fact, Oliver Benson's "Simple Diplomatic Game" was an explicit forerunner of TEMPER, Raytheon's early military simulation (39). Other academic efforts paralleled many of the military-sponsored developments. Academics such as the team under Charles McClelland at the USC-LA School of International Relations began using time series analysis to simulate event flows in international relations in the early 1970's (40).

Other academic simulations, such as the world-famous simulation (the "Club of Rome model") by Jay Forrester, depicting world crisis through declining resources (41), also brought simulation techniques into the classroom as well as research. World modelling simulations such as Forrester's, in fact, became the center of academic action in international relations computing, eclipsing the earlier man-machine models and military-related games discussed above. (42) In addition, certain specialized topics such as the modelling of arms races, also continue as lively simulation arenas. (43) Nonetheless, as Phil Schrodt recently said of 1950-1984 computer simulations in international affairs, "we've now had about 25 years of research in this field. What have we gotten out of it? -- not a whole heck

of a lot in my estimation." (44)

Jonathon Wilkenfeld's recent article on "Computer Assisted International Studies" builds on the academic tradition of computerized simulation (45). Interestingly, Wilkenfeld emphasizes the instructional value of international relations computer simulations as an aid to student debate of economic and social issues - an emphasis not very different from the shift in military simulations toward a focus on the computer-generated scenario as a policy discussion aid.

Educational Uses of Computer Simulation in Social Science

Computer simulation has had a wider impact in social science instruction than in research. Simulations by nature are simplifications of reality, often with exaggerated cause-effect linkages. Yet these very features can be effective in a teaching context. Moreover, the interactive nature of learning through simulation forces the student into a more active role than do lectures or readings. It lends itself to reiterative analysis processes without unduly slowing the student down to a snail's pace as do manual calculation (or even batch mainframe) methods.

In 1970 Fred S. Coombs and John G. Peters tested and confirmed the hypothesis that computer-based American government games would enable political science students to achieve at a higher level while evaluating the games at least as favorably as traditional teaching methods (46). Likewise, Mark H. Maier and Thomas Venanzi, experimenting with a "Science and Society" course through simulations on topics like nuclear strategy, nuclear power and radiation, the IQ debate, and sociobiology, confirmed

that learning improved when students take an active rather than passive role (47).

In spite of this evidence from the university level, apart from military and international affairs simulations, pre-collegiate teaching provides the greatest level of social science computer simulation activity. There are a number of reasons for this. Even the most simplified simulations have teaching value at some level, even if it is the elementary grades. Pre-collegiate teachers are more accustomed to using teaching aids which go beyond the book-and-lecture format so beloved by university professors. The budget for microcomputers and accompanying software, factors which have had enormous potential for increasing student and teacher access to computer simulation, are frequently greater in high schools and even elementary schools than they are in college-level social science departments, ironic as that may seem.

Whatever the reason for the greater currency of computer simulation at pre-collegiate levels, social science simulations like "Oregon Trail" have been found to be excellent tools for teaching and reinforcing interpersonal skills (48). Though a few simulations such as "Change Agent" (49), "Market", "Elect" and "USPop" (50) may be found from the late 1960's and early 1970's, this is really a post-microcomputer phenomenon, which is to say post-1979.

Some of the earliest pre-collegiate social science simulations for microcomputers were "Hammurabi", a resource-allocation game in which the student plays an ancient ruler, and "Westward 1847", a game in which the player must lead a wagon

train to the West Coast (51). The Minnesota Educational Computing Consortium (MECC) quickly became a leader in pre-collegiate microcomputing, including some social science simulations such as "Oregon Trail", adapting earlier games and creating new ones (52). A few commercial firms such as Softside ("Miner", "Convoy") (53), Instant Software ("Santa Paravia", "Fiumaccio") (54), Strategic Simulations ("President Elect")(55), and McGraw-Hill ("Geography Search")(56) also began to enter the precollegiate market with simulations, often with arcade qualities.

Interestingly, one of the early entries derived from the military simulations discussed earlier. The "War-and-a-Half Logistics Game" from Avt Microcomputer Software allowed the player to maintain the world balance of power among ten nations through judicious allocation of supplies and resources. Its reviewer found in it little of educational value (57). However, others such as one dealing with the anatomy of revolution were received favorably in the pre-collegiate market (58).

In spite of these early simulations and games, social studies still trails other areas in computer utilization and there is a growing perception of the need to go beyond very simplified canned simulations (59). One successful effort has been the linkage of 14 Michigan high schools to a more sophisticated political science simulation at the University of Michigan (60). Though this project involved telecommunications linkage to a university computer, the real need is for microcomputer instructional materials which reflect "good social

science".

General Simulation Packages and Languages for Social Science

University-based general computer simulations for social science have been widely available for over a decade. Their effectiveness compared to traditional alternatives has been systematically documented. Nonetheless, these instructional simulation packages remain underutilized in social science curricula.

SIMSCRIPT was among the first important simulation languages and is still utilized extensively in military and industrial applications such as CACI Inc.'s TAC THUNDER simulation of NATO air defense.(51) In social science, however, SIMSCRIPT has been little used compared to other languages and packages.

PRINCE, developed by Bill Copeland at Syracuse University, for example, was systematically evaluated at six colleges in 1975. Use of PRINCE, a man-machine model with updatable scenarios and data sets, was found to improve students' abilities to define political issues and to do so more concisely, and to be able to make more specific suggestions as to how to deal with more actors in seeking solutions to a political problem (52).

EXPER-SIM (Experimental Simulation) is a general-purpose simulator for experiments in social sciences or other disciplines (53). Roy E. Miller and David A. Bositis randomly assigned students to two sections of a course, both studying the same analytic problems but one using EXPER-SIM and the other the more traditional SETUPS. (SETUPS are Supplementary Empirical Teaching Units in Political Science, sponsored by the American Political

Science Association, containing printed materials on the problem, sample data sets, and exercises to be completed using a statistical package such as SPSS). Comparison of pre- and post-test scores in both groups showed EXPER-SIM students made greater gains in substantive learning, in analytic reasoning, and in computer-related learning than did the SETUPS students (54).

In the same period, almost a decade ago, George Conklin of North Carolina Central University, modified EXPER-SIM to serve functions similar to PROFIS, a set of introductory sociology simulations he developed between 1972 and 1982. Conklin's classroom testing showed that computer simulation could be used successfully to enhance the teaching of analytic techniques without detracting from a crowded curriculum (55).

EXPER-SIM, sponsored by Exxon Foundation, grew out of MESS (the Michigan Experiment Simulation System, a mainframe batch version) and LESS (the Louisville Experiment Simulation System, an interactive version). FIRM (Florida Interactive Modeler), distributed by CONDUIT, was an EXPER-SIM system rewritten for DEC and Apple computers and enhanced by psychologists at the University of Florida as a small computer version of the earlier mainframe simulators. FIRM comes with experimental simulations on cognitive dissonance, frustration-aggression, conformity, delayed opinion change, and other topics, but can be utilized to illustrate almost any data-validated theory in the social sciences (56).

MICRO-DYNAMO, a mainframe simulation language translated to the microcomputer and distributed with an excellent text by Addison-Wesley, provides a somewhat more difficult but powerful

vehicle for multivariate simulation of many social phenomena (57). It is supplied with eight simulations, including Jay Forrester's "Club of Rome" model of world resource crisis, an ecology simulation, a heroin addiction simulation, and an urban growth simulation.

Other more specialized simulation languages are available for microcomputers also, though little used in social science. GPSS (General Purpose Simulation System), for example, allows the instructor to simulate any phenomenon characterized by queueing and service allocation problems (e.g., modelling student registration day procedures, social service delivery plans, police patrol locations) (55)

The FIRM simulation approach (based in regression-type modelling), DYNAMO (based on closed systems of equations modelling dependent variables over time), and GPSS (based on probability theory and queuing problems) all focused on mathematical simulations with a minimum of text. Recently, however, a new simulation language, ESL (event simulation language), developed by Philip Schrodt of Northwestern University, has been developed to provide text scenarios which branch upon user response to decision points. This text-based event simulation language still incorporates event stacks, stochastic processes, quantitative trigger points, and other aspects of mathematical modelling, but in a format designed more for instructional than predictive use on topics such as foreign policy simulation. (58)

Special Purpose Simulations for Social Science

It is not accurate to treat social science simulations as spin-offs from military-funded efforts. Ithiel de Sola Pool, later to become involved with military simulation, had wide impact in social science through his voting simulation efforts on behalf of John F. Kennedy in the 1960 elections (70). Since then both political scientists and media organizations have pursued the simulation of voting behavior (71). Other early though largely isolated examples of social science simulations can be cited, such as Werner Grunbaum's use of Monte Carlo techniques in simulating judicial decision-making (72).

Nonetheless, it is still true that the possibilities opened by military/international affairs simulations led to the exploration of applications to other areas, among the first of which were those dealing with urban problems (73). Back in 1968 a Research Analysis Corporation paper by Lester G. Hawkins, Jr., discussed existing urban-development and community-renewal planning simulations and the extension of gaming to nonmilitary environments (74). In the 1968-1973 period the Rand Corporation, a major military contractor, undertook extensive projects with the City of New York, some involving extensive urban policy simulations (75). As with the military simulations, Rand's urban simulations proved controversial and problematic.

Educational urban simulations fared considerably better. The CITY III simulation from Envirometrics, for example, allowed 30 - 200 college-level students to "run" five cities and make economic, political, and social decisions (76). In the mid-seventies the METRO-APEX computer-assisted simulation similarly

allowed political science students to make political, planning, industrial, environmental, and economic decisions over a five-week period (77).

Urban policy issues are a particular case of a broad range of managerial simulations of complex groups or organizations, some of which are of interest to social scientists (78). For example, UNESCO's Educational Simulation Model (ESM), developed in the early 1970's, modeled educational demand and educational system fluctuations and was used in several countries (79). Within a decade such educational simulations had been incorporated in management training simulations for educational administrators (80). To take another example, the British Library has developed a systems dynamics simulation modeling activities of social science disciplines as information systems (81). Whether in school, library, or other organizational settings, such simulation efforts have broad implications for social science.

Special purpose simulations have been developed in a large number of other areas pertinent to social science. Game theory and simulation of various aspects of political and other types of bargaining are an example (82), as are simulations of various statistical and methodological techniques and processes (83), simulation of public opinion formation (84), simulation of social diffusion processes such as neighborhood segregation (85), models of the economy (86), managerial models (87), legislative voting (88), policy making/resource allocation simulations (89), psychological (90), sociological (91), and other simulation topics.

Artificial Intelligence

Artificial intelligence (AI) software is the latest development in social science simulation. Growing out of the systems modelling tradition, AI has already become a broad term with many diffuse meanings. It is used to refer to expert systems (92), for example, typically branching rule-application decision software combined with a semantic processor for interfacing in conversational English. On the other hand, AI can be used as an algorithm-generating as well as algorithm-applying approach. Likewise, as Phil Schrodt's recent work suggests, AI can involve pattern recognition in event series - simulating a decision-making process in which the decision-maker compares current event sequences with past ones and their associated consequences, uses the past as a template for current actions, the adjusts the event database for current consequences (93). This "adaptive precedent-based logic" exemplifies AI as a continually evolving problem-solving system, not an equation-based deterministic model.

Conclusion

From a base in military-sponsored models, computer simulation has evolved to provide a wide variety of applications in social science. General-purpose simulation packages and languages such as FIRM, DYNAMO, and others have made significant contributions toward policy discussion in the social sciences and have well-documented efficacy in instructional settings compared to traditional methods. With the microcomputer revolution has come a revival of computer simulation, first in pre-collegiate

education but now in a variety of other areas including urban policy, social processes, and research methodology.

In spite of the significant body of research and software in social science simulation, however, what is more striking from a disciplinary point of view is that this research and teaching tradition exists almost entirely outside the "mainstream" journals and textbooks that epitomize the social science disciplines.

The second striking fact that the foregoing overview of social science computer simulation provides is the relatively greater impact of such models on teaching compared to research. Without belittling the significant general and applied research applications of simulation, the history of military-sponsored as well as academic simulations shows a tendency toward deemphasis on such purposes as forecasting and predictive analysis and increased emphasis on the uses of simulation as a vehicle for generating scenarios, enhancing policy discussions, developing decision-making skills of policy makers, and for other essentially educational functions.

These findings reflect the state of the social sciences. Computer simulation requires a level of causal specification rare in most social science research arenas. Attempts at simulation in research-poor environments inevitably lead to models characterized by low reliability, oversimplification, and neglect of causal factors not tapped by current measurement systems.

Oversimplification, inappropriate specification, and inaccuracy of measurement are the rule, not the exception in

social science simulation. In fact, there is probably no social science simulation which cannot be subjected to substantial criticism on one or more of these grounds. These three obstacles are the reason why computer simulation has remained a specialization within social science which is removed from the mainstream of what social scientists do. Since computer simulation also requires programming skills, scarce among social scientists, it is hardly surprising that this has not become a widespread technique.

On the positive side, however, simulation is an interactive way of learning which forces one to operationalize variables and to state precisely what we know and what we do not know about a given subject. That is, it is impossible to approach a simulation unless one has clarity of thought about one's topic. Even if simulations never predicted reality with any degree of precision they would still be highly useful because they are a way of learning to think scientifically and they are a way of disciplining investigation. Thus, simulation is a way of accumulating knowledge.

Realistically, computer simulation in social science is apt to remain the step-child it has always been. The widespread availability of microcomputers virtually assures at least a modest increase in the utilization of simulation but there is not now on the horizon a strategy for realizing the potential which computer simulation holds for the social sciences or even for the consolidation of many of the clusters of simulations discussed in this essay, their refinement, and their dissemination in more user-friendly and available formats.

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10. Jerry W. Gustafson, Improvement of Social Science Education via the Development of A Social Science Laboratory. Final Report. (Washington, DC: National Science Foundation, Grant SER-78-064891, 1982). CAUSE supported the creation or enhancement of a number of social science computer laboratories; that described by Gustafson was unusual in establishing a gaming/simulation lab facility.

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14. Raytheon Co., TEMPER (Washington, D.C.: National Military Command System Support Center, 1965). Seven volumes, including Game Handbook (Vol. III, AD-470 241L); Technical Manual (Vol. IV,

AD-473 050L); Operations Manual (Vol. V, AD-470 069L; Reference Manual (Vol. VI, AD-470 070L); and Data Collection Manual (Vol. VII, AD-470-071L). See also W. C. Clemens, Jr., "A Propositional Analysis of the International Relations Theory in TEMPER - A Computer Simulation of Cold War Conflict", pp. 59-101 in W. D. Coplin, ed., Simulation in the Study of Politics (Chicago: Markham, 1968).

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17. Norman Farrell, Philip H. L[illegible]ery; and John E. Shepherd, Method for Integrative Simulation (MINTSIM) (Mclean, VA: General Research Corporation, Report No. OAD-CR-142, January 1976).

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